Newsletter for January 2024

- Project Completion: Overview of Craniofacial Bone Implant Materials and Techniques
- Craniofacial Anatomy Modeling: a milestone in alignment

# Craniofacial Special!

By Lathreas | January 30, 2024

To recap, we are aiming to create a (surgical/technological) procedure to change a patient's body into their desired anthropomorphic form in give-or-take 30 years time. Given the extremely lengthy process of safety testing and approval for many of the technologies in consideration, this means that we need to start developing the exact treatments as soon as possible. We anticipate about half of the 30 year timespan will be spent on safety testing. In the first few years of that plan (which is right now), this means we must perform rigorous engineering and design projects, which are slowly starting to get to full speed.

For the surgical procedure, this pipeline is as follows: first, we need to determine exactly what shape of bones, muscles and skin we want to achieve. Secondly, we need to design (bio)implants and procedures that we would use to convert a human bone and muscle system into that desired shape, without putting patient safety at risk.

The most pressing question has been what craniofacial anatomy we would be able to achieve in the first place, which is a topic that we have covered numerous times before. The goal of finding the exact anatomy of the bones, muscles, and skin remains an ongoing process that we aim to complete over the next period of time, with concrete and targeted research projects.

Together, this is putting us on track to settle down on a specific strategy for the craniofacial region. In this newsletter, we will cover some exciting progress in several areas related to the craniofacial region.

*Editor's note: This wuff is ready to get down to business!*

# Project Completion: Overview of Craniofacial Bone Implant Materials and Techniques

By Lathreas | January 30, 2024

For the craniofacial region, the idea of an implant being the most feasible route has been brewing for some time. As such, half a year ago, we have put a specific review project on the agenda: an orientational review of the state of the art of craniofacial bone implant materials, with the clear goal being that we want to use this information to start developing a bone implant in the shape of a muzzle in the very near future. This project, performed by Aegaeon, has produced some very deep and thorough insights into some of the most important aspects in craniofacial implant design: choosing the right material and manufacturing method. (Thank you so much, Aegaeon!) This review is now complete, has been reviewed twice, and is now officially on our website!

Aegaeon's review focuses on the advantages and disadvantages of specific artificial implant materials, bioimplant materials, the required manufacturing methods of bioimplants, and the practical challenges that must be overcome. It critically compares the available options, and makes recommendations on which specific materials to further examine.

There appear to be some clear contenders, which we will collectively examine in near-future projects. Bioimplants are, of course, quite tantalizing options, but we must remember that many technologies in that area are still in an immature stage compared to traditional implant materials. For our purposes, we will as such consider both options, which Aegaeon reviewed in detail. From the review, it appears that for the maxilla and mandible, titanium alloys and porous tantalum alloys are clear contenders for implant design, which we will examine in detail soon. Although wear and tear of any artificial material can't be repaired by the body, the mandible's and maxilla's lack of joints — places where wear and tear easily occurs — means that this becomes only a limited worry (with the exception of the jaw hinge, of course, which we aim not to alter). Even so, we must take a close look at both the geometric design of the implant, the surfaces it interacts with, as well as the overall durability of the implant for long-term use. As such, we have clear pointers of which research questions to ask next!

Aegaeon also reviewed the process of bioimplant design, which has been an incredibly insightful read. For those unfamiliar, the idea with bioimplants is that the patient's own bone material is grown into an artificial shape. This requires a "scaffold" for the bone to grow in, which can be made of any suitable material, which the bone tissue will then invade. This can be done both in the patient, or in a lab for later implantation. Aegaeon reviewed three important engineering aspects of bioimplant design: choosing the right scaffold material, choosing the right scaffold fabrication method, and choosing the right kind of scaffold maturation (which is the process of inserting the right human cells into the scaffold to allow bones to grow into the right shape). I won't go into too much detail here; because Aegaeon already did an amazing job at laying out all the viable options.

We have just completed the final typesetting for the article and have put it on our website alongside other writings that form part of our technical roadmap. I assure you it will be an insightful read!

With this review in our hands, we have a clear starting point from which to look deeper into the implant design process. All in all, this too puts us right on track to start craniofacial implant design, and gives us clear research questions to focus on next.

# Craniofacial Anatomy Modeling: A milestone in alignment

By Lathreas | January 30, 2024

As Zennith discussed in the previous newsletter, we are working on modeling the craniofacial anatomy of an anthropomorphic wolf, in order to identify what is possible, and what strategies we should employ. One important piece has been missing so far: an alignment between a detailed craniofacial bone model, and a photorealistic skin model that displays how the final anatomy would look if implemented properly.

### The main goal: reconciling anatomic constraints with aesthetic constraints

Importantly, we are tied to two sets of constraints: one set of anatomic constraints (we must make sure not to change the human skull too much, so as to decrease surgical impact) and one set of aesthetic constraints (the resulting shape must look appropriate for the species at hand). Reconciling the two is challenging, but can be done by keeping both sets of constraints in mind.

The rough process is as follows: working with a 3D model of bones, we can determine which anatomic features we want to keep the same as in humans, and which parts we allow to change. There are several operations possible to us:

- *Adding* to a bone is fairly unlimited, as we can readily add mass with a hypothetical bone implant as long as this does not impede other tissues. Especially on the snout, there is a lot of room to add material without significant concern.
- *Removing* parts of a bone can be done in a more limited fashion: bones can indeed be shaved or small slices removed, but there is a strict limit to how thin a bone can be. Especially in regions near the brain, we cannot remove much tissue.
- *Moving* bones is possible under certain circumstances, when the structure is moved as a whole and is not deformed. For example, in the case of routine cosmetic jaw surgery or jaw alignment surgery, both the mandible and the maxilla can be moved by several millimeters by using careful slices through the relevant bones, and ‘sliding’ these pieces over the cut surface to their new location. The angle of the cut determines how it can be moved, and in combination with screws to keep them in place, this is a powerful method to change the position of complex structures that should not change their internal structure, such as the eye socket.

Although we can use these three operations to make changes, we should always aim to limit the total amount of operations that are necessary, so as to remove the surgical impact to the patient. Furthermore, there are some things we cannot change, which are the *hard constraints*, and things we can only change by a small amount, which are *flexible constraints*. A good example of a hard constraint is the size of the braincase, which we do not want to change under any circumstance due to the severe effect that would have on the brain. A flexible constraint, however, would be something like the distance between the eyeballs: this is limited by the ability to stretch the optic nerve, which only yields a little bit.

From an aesthetic perspective, there are also *constraints* that we can define. Of course, those constraints may appear rather arbitrary; after all, aesthetics are just artistic interpretations. Even so, our main goal is to make an anthropomorphic creature that looks just right, and that is managed by taking a close look at the visual proportions of animal faces.

## Aesthetic Constraints: proportions of the creatures we know

There are many aesthetic constraints, which are too numerous to list in this article, such as the shape of the nose, shape of the ears, shape of the snout tip and so forth. The most relevant constraints for the purpose of our coarse alignment of bones, however, are the overall proportions of major facial landmarks: the eyes, the nose, the ears, and the mouth. In **figure 1**, I have depicted a visual representation of the constraints I looked at. The absolute size does not matter, but the relative positioning of each landmark compared to each other matters a lot in our perception to identify a wolf.

In the skin mesh, I have paid special attention to these proportions, so as to get as close as possible to a wolf as we know it. This results in a set of soft constraints, which we should aim to uphold if we want the final result to look like a genuine wolf. The total set of constraints are too numerous to name, but here are a few:

- **Soft constraint:** The lip edges should be directly below the eyes, from the front view.
- **Soft constraint:** The distance between the nose and the eyes, and the distance between the top of the head and the eyes, should be roughly equal.
- **Soft constraint:** from the side view, the angle between the top surface of the snout and forehead surface should mimic those of wolves (i.e., the angle should be small).
- **Soft constraint:** The shape of the eyelids, compared to the iris, should mimic those of wolves: there should barely be any sclera visible.

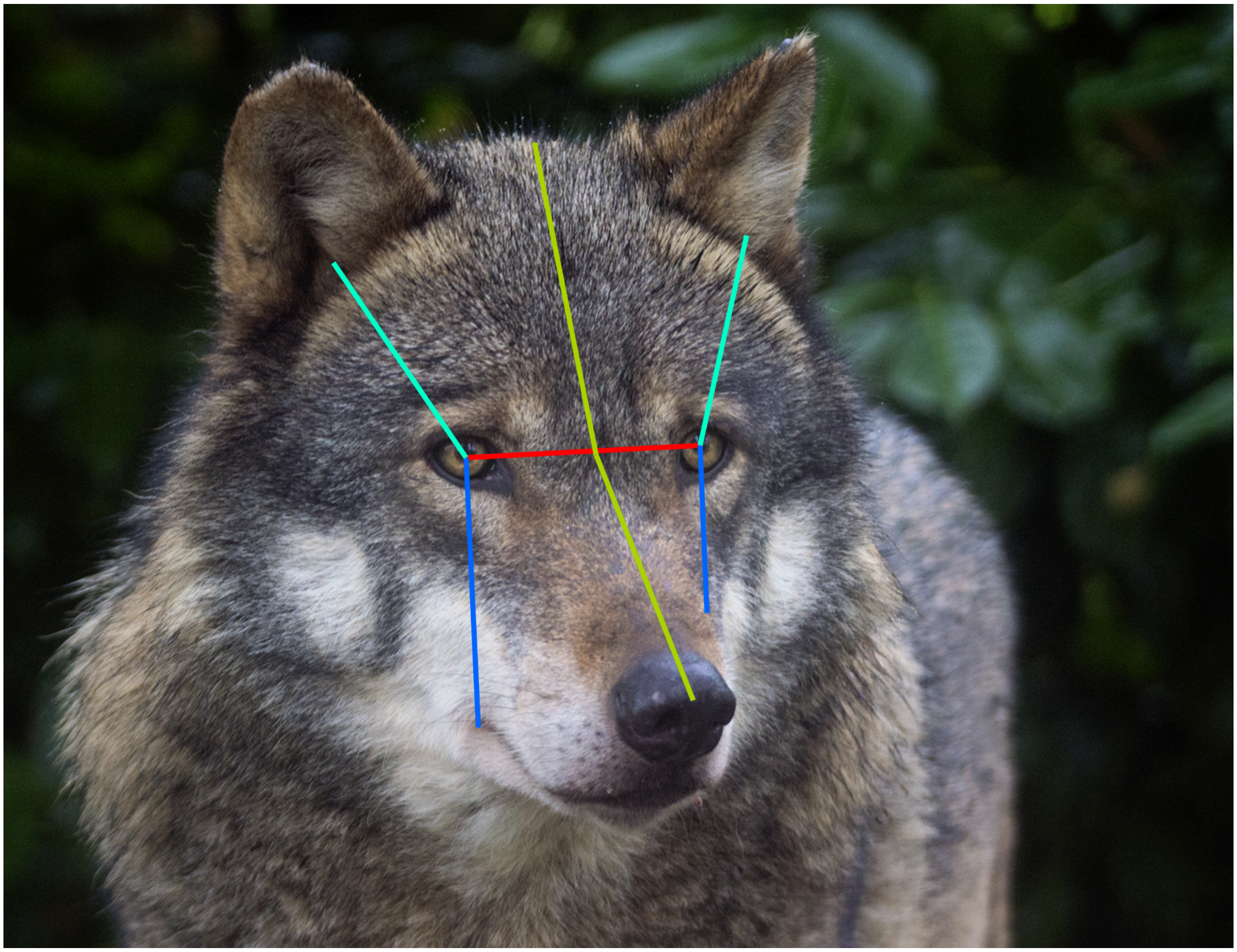
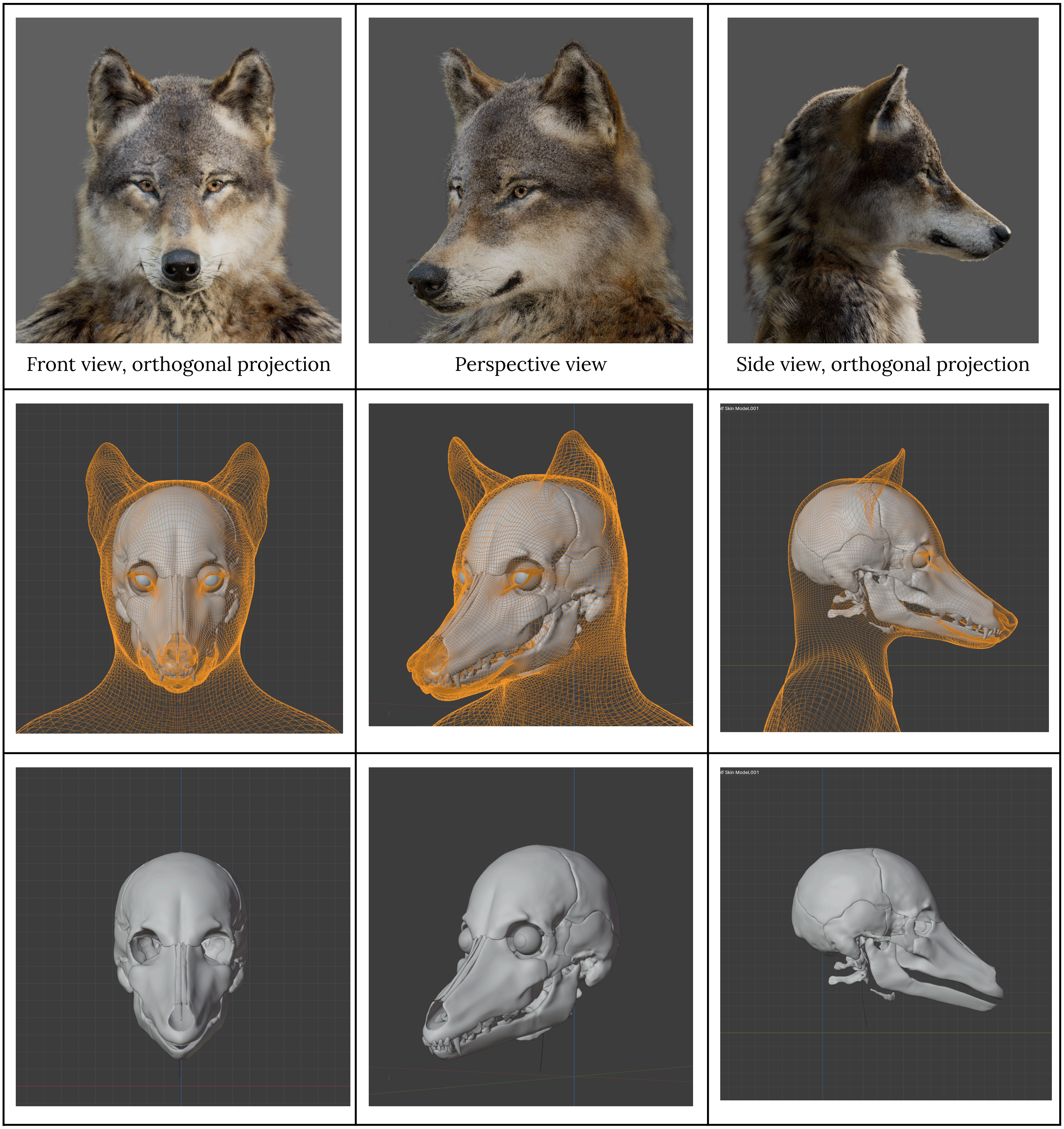


***Figure 1**: Images showing the proportions of one particular wolf. Red: interocular distance. Green: the snout-to-head length. Teal: the position of the ears compared to the eyes. Blue: the location of the lip tips compared to the eyes. Underlying photograph by hehaden on Flickr.com, licensed under CC BY-SA 2.0 DEED.*



Front view, orthogonal projection

Perspective view

Side view, orthogonal projection

*__Figure 2: Alignment between skin model and bone model.__ Top row: the fully rendered skin model. Middle row: the skin model and the bone model underneath, showing good alignment. Note that although we left space for relevant soft tissue between the skin and bones (such as muscles, the ear canal, and so forth), the exact thicknesses are subject to change pending explicit modeling of the soft tissue. Bottom row: skull model by itself. Note how the snout is tapered, to yield the correct proportions. The middle-bottom image has teeth and eyes visible as well.*

The exact definitions of the aesthetic constraints differ depending on the creature. Wolves lend themselves well for anthropomorphization, because the overall set of aesthetic constraints mimics those of humans. A housecat, for example, has larger eyes compared to its face, a smaller forehead, and a more “vertically compressed” face overall, making it more difficult to reconcile with a human’s facial proportions. Even foxes might be more difficult than wolves, due to their proportionally wider heads. We will have to see which level of technology we will need to accomplish such shapes, but for now, we have tackled one clear anthropomorphic shape with confidence.

### Anatomic constraints: the shapes of the skull we have

We can play around with the constraints that we choose, even in the anatomic area. Choosing too few constraints simply means that it will take more technology to make the changes to the anatomy safe for a patient. For this particular alignment, we chose a particularly conservative set of constraints, such that we have confidence that we can achieve such a thing with common surgical techniques and low risk to the patient.

Here is a glimpse of the set of anatomic constraints we used, some of which may be loosened if we get access to more advanced technologies:

- **Hard constraint:** Braincase size and shape remains unaltered.
- **Hard constraint:** Eyeball size and shape remains unaltered.
- **Hard constraint:** The eyeball’s Alpha Angle remains unchanged.
- **Hard constraint:** Jaw hinge remains unmoved.
- **Hard constraint:** Neck angle remains unaltered.
- **Hard constraint:** Airpipe and neck remain unaltered.
- **Soft constraint:** Optic nerve stretching is limited.
- **Soft constraint:** Jawline alterations remain limited.

We have depicted the changes between the human and anthro skull in **figure 3**. Overall, the skull looks close to a human’s where it counts. That is indeed exactly what we would want, because that would mean that less (surgical) changes are required to make it work. Furthermore, the skull would not be visible to the patient anyway. We only care if the outsides look like the creature at hand; the skull itself doesn’t need to win a beauty contest without any skin on top.

### The importance of photorealism

Even so, the skull necessarily has a significant impact on the final looks of a creature. When done wrong, this can have disastrous effects. For this very reason, it is essential that we carry out our modeling with the rigor it deserves. The biggest pitfall we could end up in is that we create anthropomorphic creatures that fall into the uncanny valley, where they are almost, but not quite, realistic-looking and as such feel… wrong. This is an effect that we can only test for when the model itself is as realistic as can be. After all, cartoons never show the uncanny valley effect, while something like a highly realistic doll would.

The skin model has allowed us to put this to the test, and importantly, has shown several interesting features that should be incorporated into the skull. While modeling the skin only, I noticed that the anthro wolf became much more realistic if I added a shallow vertical ridge on its forehead, as this makes the hairs reflect the light just slightly differently.

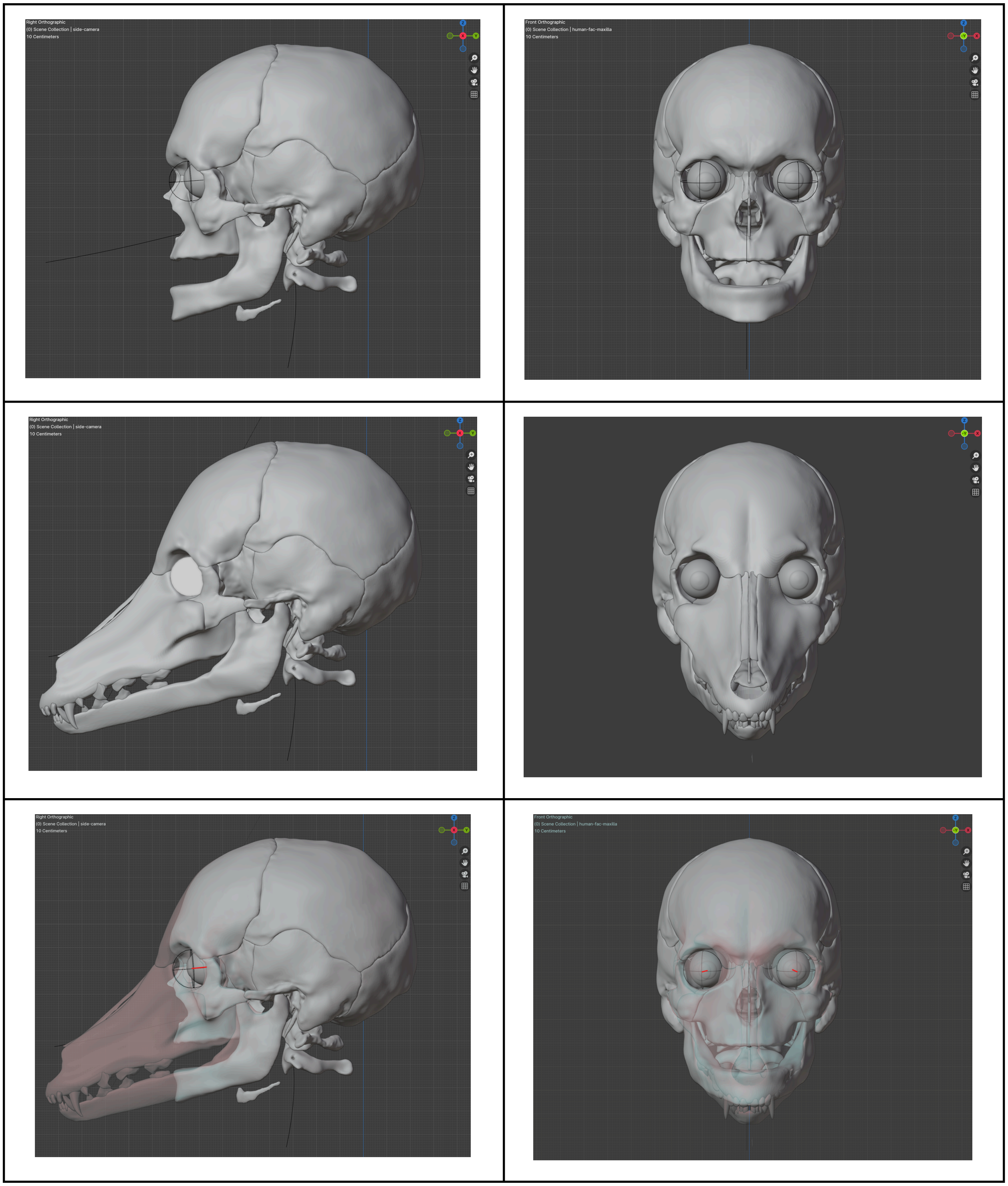
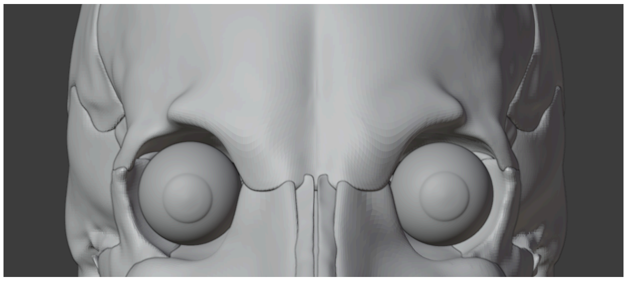

Right Orthographic
(0) Scene Collection | side-camera
10 Centimeters
Front Orthographic
(0) Scene Collection | human-fac-maxilla
10 Centimeters
Right Orthographic
(0) Scene Collection | side-camera
10 Centimeters
Right Orthographic
(0) Scene Collection | side-camera
10 Centimeters
Front Orthographic
(0) Scene Collection | human-fac-maxilla
10 Centimeters

***Figure 3: Skull model in detail.*** *Top row: human skull (sculpted by Zennith). Middle row: draft anthro wolf skull (drafted by Zennith, edited by Lathreas). Bottom row: differential color overlay of the human and anthro wolf skull shows that the primary anatomic constraints (such as braincase size and jaw position) are maintained. Red lines indicate the total movement of the center of each eyeball between each model.*

Upon close examination of an actual wolf skull, it appears that this ridge is indeed present in real wolves too! For this reason, in the middle-left image of figure 3, you can see that I added this ridge, as well as other landmarks present on a wolf skull, to get those features that a wolf has in real life as well. The region between the eyes, for example, has been nearly completely filled up with extra bone mass. Although this does not impede the eyeballs, it has the significant aesthetic effect of integrating the snout with the rest of the skull, as is the case in real wolves. The importance of such an addition would not have been clear at all if we didn't have such a realistic skin+fur model to test it with!



These additions do not conflict with any of the constraints we posed. Even so, the (surgical) technique we end up choosing will dictate whether each proposed alteration is feasible in the end, and as such, this will be our next focus.

**Our model shows a feasible set of changes with appropriate aesthetics**

Even so, there is a clear milestone here: we have managed to pinpoint a feasible set of constraints that has appropriate aesthetics, and verified that this set is broadly compatible. This allows us to focus now on getting to quantitative detail, such as the exact widths of the skin at each point, the muscle tissue that must be present, and so forth. The bone model is as such not yet finalized: many details will be part of our future focus, and the skin model too will be subject to artistic improvement over time.

**Limitations**

The key question we set out to answer is whether the set of anatomic and aesthetic constraints are compatible, which we now have with good confidence. As such, there are still several key limitations to the bone model that lie outside of the scope of this question: for example, important holes in the skull through which nerve bundles are wired to the face, called foramen, are not yet modeled. The teeth are also just hastily added, and warrant proper modeling in the future to ensure they align when chewing. Questions about vocalization remain as well, which will require modeling of the tongue and surrounding tissues.

More quantitative detail is necessary as well, which is a task of the ARF (Anatomy Re-engineering Framework) to resolve, once we get there.

**Next steps**

As with any early engineering effort, we were considering many different possible angles of attack: bone surgery, force-based rearrangement, genetic treatments, implants, and so forth. With this knowledge, however, we can greatly narrow down what types of treatments or methods we should pursue, and in which areas. Importantly, the fact that the bone matter in the anthropomorphic skull quite nicely lies on top of a human one, we know that the most feasible method would involve creating a craniofacial implant that would get integrated into the existing bone tissue. And luckily, designing bone implants is a well-understood practice that is already in use broadly within patients. With such a clear path forward, we are currently planning our next steps, which will gradually move towards more and more concrete engineering projects that are aimed at designing bone implants.

# Future Trajectory

A few near-term research questions remain in relation to facial structure, mostly related to the eyeballs. In particular, the size of the iris determines in great part how much flexibility we will have in shaping the face. Many animals have larger irises, and from our modeling efforts, we know that increasing the size of the irises yields more realistic-looking animal faces. Of course, eyeballs are finicky, and as such, this area remains shrouded in uncertainty until we find a clear way to tackle these challenges. We have some review projects on the agenda to see where we can get; but even if we cannot change the iris size, we already have a good base to work with that looks realistic from which to expand.

Our eyes are currently pointed towards implant design as well, and some fun stuff is in the pipeline. Keep your eyes peeled for project openings! With our goals being increasingly well-defined, we are beginning to get to a point where project management itself can be much more streamlined and focused as well. More stuff to come!